

Estimation of Vegetation Variables Using AIRSAR Data Containing Multiple Scattering Mechanisms

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ABSTRACT

Polarimetric and multifrequency SAR data are used to construct a multi-tier estimation algorithm for successive derivation of the variables describing the entire forest canopy. This is in contrast to previous algorithms by the authors which dealt with the estimation of variables using a single scattering mechanism and the variables of a single canopy layer. The solution method starts with the upper canopy layer and higher frequencies, and works down to the lower layers using lower frequencies. Several stand types are considered, each of which has different scattering characteristics. The flexibility and applicability of this approach to various canopy types is demonstrated.

1. INTRODUCTION

Radar backscatter data at different frequencies and polarizations carry information about various segments of a complex vegetated surface, manifested in different scattering mechanisms. These mechanisms are commonly considered to be (1) volume scattering from the branch and leaf layer, (2) direct ground scattering, and (3) double-bounce scattering between stems and ground or branches and ground. On a general qualitative level, the higher-frequency, cross-polarized channels are more sensitive to branch-layer volume scattering, whereas the lower-frequency, co-polarized channels are sensitive to double-bounce mechanisms and ground scattering. Although such qualitative generalization may be intuitive, quantifying such relationships for different vegetation types is not trivial.

Here, we combine mechanism-specific estimation algorithms to solve the quantitative multiple-mechanism estimation problem. The volume- and double-bounce algorithms augmented with a simplified ground backscattering model are used to estimate their

respective vegetation and surface variables. C-, L-, and P-band AIRSAR data from the 1994 BOREAS field campaigns are used, along with ground measurements of the vegetation canopy at the main flux tower sites. The approach consists of successively solving for unknowns to which each of the frequency bands is sensitive. First higher frequencies are used to estimate variables of the upper vegetation layer (branch and leaf layer). This information is then used, along with a numerical forest scattering model, to reduce the number of unknowns involved in the solution of the lower frequency scattering mechanisms, hence solving for unknowns in the lower layers of the canopy, e.g., stems and ground characteristics.

2. STUDY SITE AND SAR DATA

The data to be used in this study were collected by the NASA/JPL AIRSAR over the southern study area of BOREAS in Saskatchewan, Canada in summers of 1994 and 1995. Polarimetric C-, L, and P-band data and single-polarization C-band interferometric data were collected over the five main flux tower sites, at which locations extensive ground measurements were performed. Each tower site has a different dominant species type, each with distinctly different scattering characteristics.

3. SOLUTION METHOD

Multi-tier Approach

The forest canopy is conceptualized as a layered medium consisting of a branch and leaf layer with a specified random collection of disks and cylinders, a trunk layer with randomly located nearly vertical cylinders that may or may not extend into the branch layer, and an underlying rough ground. Depending on the depth and scattering characteristics of each layer, different frequencies and polarizations may be used to obtain quantitative information about that layer.

The approach is to first estimate the unknowns of the top-most layer with the highest frequencies available. The reasons are that the higher frequencies such as C-band are generally attenuated as they go through the top branch layer and do not carry much backscattering information from the layers below, and that due to their shorter wavelengths, they are more sensitive to the smaller scatterers usually present in the upper layers of the canopy. The algorithm described in [1] can be used to estimate relevant unknowns within this layer. Allometric equations for the species under study can be used to relate several parameters to reduce the number of unknowns to that suitable for estimation with the available number of data channels.

With the branch and leaf layer specified, a forest scattering model, e.g., [2], can be used to simulate the backscattering contribution of the layer at lower frequencies and remove that contribution from the total measured backscattered signal. The remaining signal is due to the double-bounce and ground scattering mechanisms. Unless the canopy is very sparse or parts of the surface are exposed, there is generally very little ground backscattering contribution. The lower frequencies, such as P-band, can be used in the algorithm described in [3] to derive trunk and ground characteristics using the double-bounce mechanism. Again, the number of unknowns can be reduced by utilizing canopy-specific allometric equations.

If the ground is exposed to a degree that rough-surface scattering dominates the measurements, all frequencies can be used, each suitable for the derivation of different characteristics of the ground. Lower frequencies will be more appropriate for estimation of dielectric constant (moisture), whereas the higher frequencies will be more sensitive to roughness properties.

Estimation Algorithm

At each stage, be it the solution to volume scattering, the double-bounce, or ground scattering, the problem is stated as deriving the set of unknowns that best fits the observations given the respective polynomial scattering model. Hence, the basics of the estimation algorithm are the same in all cases. Here, we have used a nonlinear optimization technique with an iterative preconditioned conjugate gradient algorithm at its core. Solutions are

found within a few iterations given a tolerable error condition. Depending on the unknowns involved and the data channels used for each mechanism, the associated covariances used to describe their statistical characteristics have to be carefully defined in each case. Data covariances are calculated from the AIRSAR data directly, whereas unknown variable covariances have to be assumed a priori.

4. AN EXAMPLE

As an example, consider the old jack pine stand in the BOREAS southern study site. A summary of stand characteristics are given in Table 1.

Table 1. Summary of old jack pine stand characteristics

Tree density (#/m ²)	0.3
Branch-layer thickness (m)	9.0
Trunk height (m)	15.1 ± 3.0
DBH (cm)	13.0 ± 4.9
Primary branch density (#/m ³)	7
Primary branch length (m)	0.7 ± 0.18
Secondary branch density (#/m ³)	70
Needle density (#/m ³)	1500

The scattering model of [2] was used to show the contribution of different frequencies and polarizations to the radar backscatter data, as shown in Table 2 for the HH polarization. The VV and HV polarizations follow a similar pattern.

Table 2. Contribution of scattering mechanisms to the old jack pine SAR backscatter.

	C-HH (dB)	L-HH (dB)	P-HH (dB)
Branch-layer volume	-10.4	-10.7	-22.0
Trunk-ground	-35.5	-6.1	-1.8
Ground	-36.0	-39.4	-33.2
Total	-10.3	-4.3	-1.5

The methodology described in Section 3 can be clearly followed using Table 1: First, C-band data are used to estimate branch-layer variables such as density and dielectric constant, since the volume scattering from this layer is overly dominant to other mechanisms. The branch-layer data are used to simulate the L-band branch-layer

contribution (with proper modification of dielectric constant). The total L-band backscatter is adjusted to leave only the trunk-ground contribution, which together with P-band data are used to estimate the trunk and ground characteristics. Numerical results will be shown at the presentation.

5. RESULTS

Detailed examples of the solution method will be given for at least three of the BOREAS flux tower sites (young jack pine, old jack pine, and old black spruce). The results will be compared to the available ground measurements. This solution provides a larger, more comprehensive, set of estimated variable maps than could be obtained with a single frequency or from considering only a single scattering mechanism, and has many potential science and operational applications.

REFERENCES

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ACKNOWLEDGMENT

This work was performed by the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, under contract from the National Aeronautics and Space Administration.